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STUDIES FOR STUDENTS.

THE ELEMENTS OF THE GEOLOGICAL TIME-SCALE.

THE formations, as we find them classified in this time-scale, are arbitrarily limited and classified, but back of this arbitrary classification, certain grand events in the history of the earth are indistinctly seen. The primary units of the classification are called systems. Beginning at the base of the fossil-bearing series resting upon either Archæan or rocks of uncertain age there are first, the (1) Cambrian system of Sedgwick, restricted and also expanded as the result of later investigation. Second, the Silurian system of Murchison, divided into two, the lower Silurian which, to avoid confusion, and to give definiteness to the nomenclature has been named (2) Ordovician, by Lapworth, and the upper Silurian, for which we will retain, thus restricted, the name (3) Silurian. The fourth system, (4) Devonian, was proposed by Murchison and Sedgwick. The (5) Carboniferous system follows, which was early defined in Geology, but it is not clear who first proposed the name early applied to the coal-bearing rocks. Above this is the (6) Triassic system of Bronn, followed by the (7) Jurassic system of Brongniart. To the next system the name (8) Cretaceous was applied by Fitton. The next system still retains the name (9) Tertiary, of Cuvier and Brongniart, and is terminated by the (10) Quaternary system, whose name was introduced by Morlot. Tertiary and Quaternary were applied on the plan of Lehmann's classification which, in other respects in the course of events, has dropped out of the nomenclature.

Without explaining how the series of stratified rocks come to be divided into these particular ten systems, it may be said that their retention is due mainly to the relatively sharp boundaries which each system exhibits in its typical locality. The systems thus serve as known and definite standards of comparison in the construction of the time-scale, as the dominance of nations or the dominance of the dynasties in each serve as time standards for the discussion of ancient human history. As the period of each dynasty in ancient history is marked by continuity in the successive steps of progress of the country, of the acts of the people and of the forms of government, and the change of dynasties is marked by a breaking of this continuity, by revolutions and readjustment of affairs, so in geological history the grand systems represent periods of continuity of deposition for the regions in which they were formed, separated from one another by grand *revolutions* interrupting the regularity of deposition, disturbing by folding, faulting and sometimes metamorphosing the older strata upon which the following strata rest unconformably and form the beginnings of a new system.

Geological revolutions were not universal for the whole earth; from which it results that these typical systems and their classification are not equally applicable to the formations of all lands. It is important also to note that the geological revolution was not a sudden catastrophe but the culmination of slowly progressing disturbances bringing the surface of the region concerned ultimately above the level of the ocean, the ocean level being a pivotal point in geological rock formation. The area whose surface is below the sea level may be accumulating deposits and making rocks, but so soon as the same region is lifted above the surface it becomes a region of erosion, destruction and degradation. Whenever, therefore, in the oscillations of level any particular part of a continental mass of the earth's crust passes permanently, or for a long geological period of time, above the sea level, a great event in geological history has culminated. In case the elevation is only temporary the event is marked by unconformity, or a break in the continuity of the formations; when it is permanent the geological record for that region ceases except so far as fresh water deposits in lakes may continue independent records. Hence it is that these periods of revolution are of such importance in the history of the continents, and constitute the most satisfactory marks for the primary classification of geological history.

The natural geological system is a continuous series of conformable strata. A geological revolution is expressed by unconformity and more or less disturbance and displacement of the strata from their original position. The grander revolutions are also recorded in the permanent elevation of mountain masses or extensive continental areas, above the level of the sea and thus out of the reach of later strata accumulation. The most widely recognized revolution in geological time, since the close of the Archæan, separates the Carboniferous from the Triassic system. In American classification, following Dana's usage, it may be called the Appalachian revolution. It terminated the series of formations which, with only minor interruptions, had been continuously accumulating in the Appalachian basin from the early Cambrian period onward. It left above the sea level not only all the Appalachian region but the great part of the eastern half of the continent, extending westward beyond the Mississippi river to a line running irregularly from western Minnesota to Texas. This revolution produced the Allegheny mountains, and those flexings and faultings which are still recognized in the line of lesser ridges extending from Pennsylvania to Georgia. In England, Northern Europe and Northern Asia like disturbances took place at the same general period of time. In Australia, Southern Africa and South America, the indications are that the revolution was not so extensive, if it took place at all at the same time. The probabilities are that while it was almost universal for the northern hemisphere it was mainly confined to this half of the earth. The Appalachian revolution was not limited to a brief geological period but beginning near the close of the coal measures of the east it did not become effective in the region of Kansas and Nebraska till the close of the Permian. The wide extent of the disturbance of strata and consequently of records at this point in the time-scale has led to making here a primary dividing point of the scale, marking off Palæozoic time.

Several lesser, more or less local, revolutions have left their permanent mark in the grander structure of the rocks or in conspicuous geographical features of the restricted region of the continental area. The first of these was the Green mountain revolution which separated the (Lower Silurian) Ordovician from the (Upper Silurian) Silurian, for the eastern part of North America. The elevation, disturbance and metamorphism of the rocks of the Green Mountains stand forth as monuments of this event. The revolution is not sharply distinguishable in the rocks of the more southern or western regions. The second of these lesser revolutions is expressed most sharply in elevation and unconformity terminating the Devonian formations of Maine, New Brunswick and Nova Scotia, and may therefore be called the Acadian revolution. In the continental interior it may be indicated by the remarkable thinning out of the Devonian rocks toward the southwestward. In Tennessee, Alabama and Arkansas they are represented by a thin sheet of black shale, a few feet thick, or by but little more than a line of separation between the rocks of the Silurian below and the Carboniferous beds resting scarcely unconformably upon them. This seems to indicate an elevation of the region still further south toward the close of the Devonian, sufficient to produce extensive erosion, uncovering the Lower Silurian rocks which were again depressed to receive the marine deposits of the early Carboniferous upon their eroded surfaces.

The Appalachian revolution closed the Palæozoic time and left the great part of the eastern half of the continent above sea-level. It forms the natural interval between the Carboniferous and the overlying system, whatever that may be. Its characterteristics have already been described.

The Palisade revolution, along the eastern border of the continent, marks the division between the Jura-Triassic part of the Mesozoic time and its closing Cretaceous age. It is expressed by the trap ridges in the Connecticut valley, the Palisades and other similar tracts distributed inside the coast from Nova Scotia to North Carolina, and by the uptilting and in some cases faulting of the underlying red sandstone and shale, and the resulting unconformity with the succeeding formations. The evidences of the revolution are not widely extended nor is the time relation of the termination of the revolution sharply defined, but it is sufficiently so to form a natural boundary line separating the Jura-Trias from the Cretaceous. After this point of time there occurred nothing in the eastern half of the continent which deserves the name or rank of a geological revolution. The western part of the continent is conspicuous for its grand geological construction after the Triassic at least; along the coast the Sierra Nevada revolution marked the same general interval of time recorded by the Palisade revolution of the east. These events on the opposite borders of the continent are alike at least in preceding the Cretaceous and in terminating the formations which are of Jura-Triassic age.

The Rocky Mountain revolution, which resulted in the elevation and disturbance of the rocks in the region of the Rocky Mountains, and extended from them to the border ranges, is distributed along the time from the close of the Cretaceous to the Miocene, or possibly later. It is altogether probable that the actual length of time, taken in the elevation, tilting and disturbance of strata after the last marine deposits of the pre-Laramie formations, which resulted in the permanent adding to the continent of its western third, was not longer than that consumed in the various events terminating the Palæozoic, and making into permanent land the great mass of the eastern half of the continent. This Rocky Mountain revolution resembles the Appalachian revolution, in extending over and affecting a large area of the continent, in its general upward-lifting of that area, which process extended over a long period of time, and in the great accumulation of coal or lignite which was associated with the gradual emergence of the continental mass above the sea-level.

Another feature in which the two revolutions resemble each other is found in the wide extent of the disturbances recorded. The elevation of the mountain ranges from the Pyrenees east-ward to the Himalayas, and to the islands beyond, took place chronologically at the same general period, and that this series of disturbances may have affected the whole of the northern hemisphere is further suggested by the occurrence of gigantic erratic blocks of granite in the midst of Eocene strata in the neighborhood of Vienna and other places. Vezien (Rev. Sci. XI., p. 171, 1877) has suggested that an ice-age is indicated by these events.

This Rocky Mountain revolution marks the period of the second great break in the life of the geological ages. The Mesozoic time began with the close of the Appalachian revolution, and closed with the elevation of the Cretaceous beds above ocean-level. In our classification the division line between the Cretaceous and Tertiary was arbitrarily placed at the top of the chalk formations conspicuously developed on both sides of the British Channel. The difficulty American geologists have had in drawing the precise line to separate the Mesozoic from the Cenozoic has resulted from the change of the character of life in the beds in the western interior from marine to brackish, fresh-water and land types. This change was incident to the Rocky Mountain revolution, which had already begun, and was slowly lifting the whole region while the Laramie sediments were being laid down. Several stages may be marked in this grand revolution, but the facts connected with them are not so well-developed as to serve for general purposes of classification of the time scale.

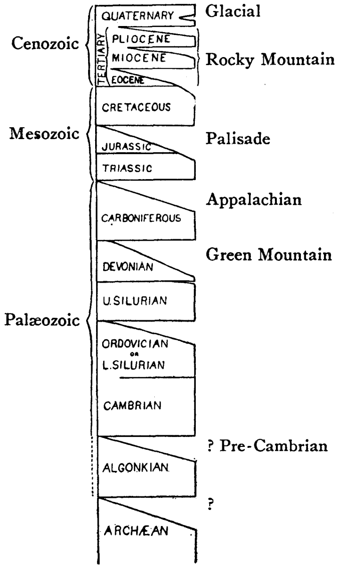
At the close of the Miocene, a great outflow of lava in the northwestern part of the United States took place, and continued with interruptions through the Tertiary into the Quaternary time. About the Columbia River, where it cuts through the Cascade range, the basalt is over three thousand feet thick, and the outflows cover a vast extent of territory, estimated at 150,000 square miles. This was incident to the vast earth disturbance which raised to the amount of at least five thousand feet a large part of the western half of the continent.

There was, still later, a revolution which has left little record in the way of disturbance or discordance of strata, but was of particular importance in life-history, as it introduced the recent period, or the age of man. This is the combination of events marking the glacial epoch. In general, it consisted geologically of oscillations of the northern lands for the northern hemisphere, and was associated with the accumulation of ice upon the surface and its continuance as a great ice-sheet for a long period of time. Some of the more accurate estimates of the length of geological time are based upon the rate of erosion or gorge-cutting by rivers, and the period so measured dates back to the last uncovering of the river channels coincident with the northward withdrawal of the ice-sheet. Standard examples are the estimates of the time required to cut the Niagara River gorge, and the retreat of the falls of St. Anthony from Fort Snelling to their present position, as beautifully elaborated in Winchell's Report on the Geology of Minnesota, vol. 2.

The above revolutions are selected, not as the only revolutions interrupting the regular course of sedimentary formation of stratified rocks, but as chief examples of such interruptions in the North American scale. All along the course of geological time there are evidences to show that there were constant oscillations of the relations between land and ocean-level, and at some localities these oscillations were passing across the datum plane of the ocean surface. Wherever this happened, on one side rocks were forming, and on the other erosion and degradation obliterating them as time-records. The Appalachian and the Rocky Mountain revolutions constitute the two grander revolutions. The first closed the Palæozoic life Period, the fossils being chiefly marine until the Devonian, and being associated with marine forms up to the close of the Carboniferous. The deposits are distributed across the continent, with local interruptions. After the Appalachian revolution the eastern half of the continent, except its Atlantic and Gulf borders, became permanently above the sea-level.

The period between the Appalachian and Rocky Mountain revolutions is the period of the Mesozoic life. In the faunas and floras of this period, land and fresh-water species take a prominent part. The marine life is distributed over the western half of the continent and along a narrow line of formations on the Atlantic and Gulf borders. After the beginning of the Rocky Mountain revolution, the deposits of marine origin and their faunas were distributed on the marine borders of the continent as it now is, and fresh-water and land deposits were accumulated over the plains and plateaus of the western half (with few exceptions) of the continent.

Thus the grander revolutions recorded in the development of the American continent break up the geological time-scale expressed in the systems of stratified rocks into a few natural subdivisions, as may be illustrated by the following diagram:



In the use of the time-scale for the study of the history of organisms, the places marked by the revolution are those in which are found the grander interruptions to the continuity of the record. They may represent periods of great relative magnitude. They do represent periods of marked change in the faunas and floras over extensive regions. Between the grander intervals of revolution the records of life-history are relatively continuous. There were series of successive faunas or even subfaunas, in which were expressed the general features of the evolution of life on the globe. The species preserved and known present but a very imperfect representation of the species that were living; but of those preserved in one formation there are generally found in the succeeding formations representatives of the same or closely allied genera; so that for the kinds of organisms whose remains are best preserved the record is fairly continuous for the grander rock-systems in terms of the generic, and in some cases of the specific characters.

While the conditions of deposition for a particular region remained relatively constant and uniform, the strata were accumulated in successive beds one upon another, and then the thickness of the deposits of the same kind, with proportionate thickness for deposits of different kinds, constitute a scale of definite time value; a foot of deposit representing a period of time, and the relative time-separation for two faunas would be represented by the thickness of the strata between them. It was on this principle that the time-ratios of Dana were estimated. The maximum thickness of the known strata of each geological system was taken. The limestones were assumed to represent five times the time-value that is represented by the other sedimentary deposits per foot; or in other words, every foot of limestone was estimated as equivalent to five feet of other sedimentary deposits in making up the time-ratios. On this principle Dana estimated the time-ratio for the several geological periods to be as follows:

Quaternary	¼	Cenozoic 1.
Tertiary	¾	
Cretaceous	1	Mesozoic 3 +.
Jurassic	1¼	
Triassic	1	
Carboniferous	2	Palæozoic 12 +.
Devonian	2	
Silurian (Upper)	1¼	
Ordovician (Lower Silurian)	6	
Potsdam	1	

Ward, in the fifth annual report of the United States Geological survey, has proposed to adjust these proportions as follows:

Quaternary-Recent	1
Miocene-Pliocene	1
Eocene	1
Cretaceous	1
Jura-Trias	1
Permo-Carboniferous	1
Devonian	1
Silurian	1
Cambrian	1

thus forming nine divisions of equal length.

Since Dana's estimate additions have been made to the known thickness of the Cambrian rocks of North America, which should lengthen the Cambrian ratio to 5 in the above table, and duplications of thickness due to confusion in regard to the Quebec group may reduce the Ordovician (Lower Silurian) to 5, and the Cretaceous ratio may be somewhat enlarged. The Tertiary estimate in Dana's ratios assumes the thickness to be of less (½) time-value because of the increased rate of deposition due to transportation of rivers. This and many other factors enter in to complicate the time-value of thickness of strata; but it must be granted that the thickness of the sediments is the prime factor in determining these time-values of the geological scale. However, the conditions of deposition, the fineness or coarseness of the clastic fragments, the abundance or rarity of supply of materials and other variable conditions must be taken into consideration in an accurate reduction of thickness of strata into length of time. Errors, also, whose value is almost impossible of estimation, arise from the intervals between strata, particularly those where unconformity exists.

After all these uncertainties are weighed the time-ratios formed on this general basis are of great importance in studying the history of organisms, and the value of accuracy in the time-scale is a sufficient reason for calling attention to the points in which greater accuracy may be attained by further investigation. It is doubtful if it is possible with our present knowledge to reach an estimate in years or centuries, of the actual length of geological time, which is within 100 or perhaps 200 per cent. of the truth. We may accept Dana's estimate of at least 48,000,000 of years, or Giekie's of from 100,000,000 to 680,000,000. We find at one extreme the ancient theory of 6,000 years and at the other McGee's possible maximum of 7,000,000,000 years.

The rate of accumulation of sediment over the bottom of the sea may vary between the limits of one foot in 730 years and one foot in 6,800 years, as pointed out by Geikie, the figures being based upon the estimated proportion between the annual discharge of sediment in cubic feet and the area of river basins in square miles, in the case of the rivers Po and Danube. The estimate of 680,000,000 of years, quoted above, is dependent upon the assumption that the total thickness (maximum) for the sedimentary deposits is not less than 100,000 feet, and that the average rate of accumulation was not more rapid than that now going on at the mouth of the Danube, based upon Bischof's determination of the amount of sediment and matter in solution in the Danube at Vienna. It may be a query worth considering whether the estimates based upon the examination of the amount of suspended and dissolved matter in river water are not likely to err in the direction of too small amount of matter by reason of the abnormal precipitation along the course of the river incident to the presence of salts and acids put into the river by man. If the rate of the river Po were taken the length of time would be 73,000,000 of years instead of 680,000,000.

The actual length of time in years, however, is of less importance to the geologist than the relative length of time for each of the ages, and these latter, the time-ratios of Dana, are clearly deducible from the physical thickness and size of constituent particles of sedimentary rocks. Relative thickness is certainly one of the elements in the determination of the time values of the geological formation, and the fields for investigation along which greater accuracy is to be reached cover the problems of the rate of accumulation of muds, sands and pebble beds, and of the formation of limestones, in relation to each other and under varying conditions, and the detection of the marks in the strata recording the conditions incident to the varying rates of accumulation. Until the evidence is fuller the time-ratios of Dana may be adopted as expressing approximate values for the various geological ages.

In all these studies in which the geological time-scale is applied to the evolution of the earth and its inhabitants, the time concerned is not human chronology but is what may be called *geochronology*. For this purpose we need a standard time-unit or *geochrone*. The geochrone applied in Dana's time-ratios appears to be 8,000 feet of sedimentary deposits, as in the Potsdam, (7000 feet sediments and 200 limestone). Something more definite is needed and one in which the equivalents in different kinds of deposit and in different regions can be studied and compared with some approach to accuracy. The Eocene period, as expressed in the gulf states on both sides of the Mississippi river, might be selected as a convenient and practicable standard for this purpose. Humphrey and Abbot's elaborate studies of the Mississippi river furnish minute data for comparison with recent conditions. There are 3,000 feet of marine beds referred to the Eocene in southern Europe. The Eocene or early Tertiary fresh-water beds reach a thickness of at least 10,000 feet. The Tertiary beds in Liguria are estimated to reach the thickness of 23,600 feet. If for the present we assume the Eocene geochrone to be equivalent to the maximum deposit of 3,000 feet of fragmental sediment on the edge of the continent, using Dana's estimates of time-ratios with some modifications, and adopting the term Eocene as the American students of marine Eocene apply it, the following standard time-scale for geochronology is constructed. The geochrone in this scale is the period represented by the Eocene, as understood in North America to include the marine deposits and their faunas, from the close of the Cretaceous to the top of the Vicksburg or white limestone of Smith and Johnston, 1,700 feet of which are seen in Alabama. In England it may include the Oligocene to the top of the Hempstead beds. I realize that such a proposition furnishes many points for dispute. The scale is open for correction, and the standard may be defined with greater precision. But it is offered as a working hypothesis, to aid and stimulate investigation.

Such a standard time-scale of geochronology, on the basis of the Eocene period for a time-unit or geochrone would read as follows:

Recent Quaternary	1	= 3.
Pliocene Miocene	1	
Eocene	1	
Cretaceous	4	= 9.
Jurassic	3	
Triassic	2	
Carboniferous	6	= 45.
Devonian	5	
Up. Silurian	4	
Low. Silurian or Ordovician	15	
Cambrian	15	

The proximity of the Eocene of the Gulf border to continental conditions now in operation, the abundance of its marine fauna for comparison with like faunas of earlier or later age and of the same or different habitats, and its inclusion of traces of land-life for correlation with other conditions, and, in general, the wide distribution of available Eocene deposits and faunas for comparative study, are reasons for calling attention of investigators to this particular field for minute investigation in perfecting the geological time-scale.

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